

National Aeronautics and Space Administration



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# Cutting edge

Goddard's Emerging

Technologies

The Silicon Promise:

## Building a New Type of X-ray Mirror

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# Year in Review: Why We Do Technology



As we begin the new year, I want to take time to reflect on our accomplishments in 2016. It truly was a notable, impressive year. I can say without reservation that our men and women remain on the technological forefront, creating highly innovative, strategically important technologies that NASA

needs to carry out mission science across all scientific areas.

Our technologists' successes — largely the result of their innovative minds and willingness to collaborate with others — underscore why we invest in technology development at Goddard. Their technologies are being infused into new missions and instruments and some are dramatically

improving the performance of already highly successful capabilities. In 2016, our people delivered new instruments, filed patent applications, received follow-on funding to further enhance their concepts, and demonstrated new capabilities on high-altitude aircraft, sounding rockets, and balloons.

Many of these successes were featured in this publication over the past year. And by all appearances, as evidenced by the content in the winter 2017 edition, our record of success will continue. I invite you to download and read a copy of our annual report, *Investing in NASA's Future Through Innovation and Collaboration*, which describes the many successes enjoyed by our remarkable group of technologists. ♦



To download go to: [https://gsfctechnology.gsfc.nasa.gov/newsletter/2016\\_GSFC\\_FINAL\\_Web.pdf](https://gsfctechnology.gsfc.nasa.gov/newsletter/2016_GSFC_FINAL_Web.pdf)

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## About the Cover

Goddard scientist Will Zhang (middle) — a long-time creator of X-ray mirrors — is developing a process to manufacture a new-fangled X-ray optic made of silicon, the material used in computer chips. Raul Riveros (left) has helped advance the process, which Zhang has tested and now believes will give scientists what they've long wanted: lightweight, super-thin, high-resolution X-ray optics for future NASA missions. Vince Bly (right), who also experimented with silicon as a potential mirror-making material, has assisted in Zhang's technology-development effort.

Photo Credit: Bill Hrybyk/NASA



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# Mirror-Making Extraordinaire Advances Silicon X-ray Optics to A New Level

*Astrophysicist Receives NASA Funding to Mature Cutting-Edge Fabrication Technique*

Mirror-making extraordinaire Will Zhang has created and proven a technique for manufacturing lightweight, high-resolution X-ray mirrors using silicon — a material commonly associated with computer chips.

The Goddard astrophysicist has shown in repeated testing that single-crystal silicon — a hard, brittle non-metallic element used in the manufacturing of computer chips — works exceptionally well as an X-ray optic.

Given the cost of building space observatories — which only increase in price as they get larger and

heavier — the goal is to develop easily reproducible lightweight optics, without sacrificing quality. According to Zhang, use of silicon would give X-ray astrophysicists what they have long wanted: super-thin mirrors that offer a significantly larger collection area and dramatically improved resolution — all at a reduced cost, Zhang said.

To date, no one has created an X-ray mirror that addresses all these performance goals. Furthermore, no one has polished and figured silicon for X-ray optics, which must be curved and nested inside a canister-like assembly to collect highly energetic

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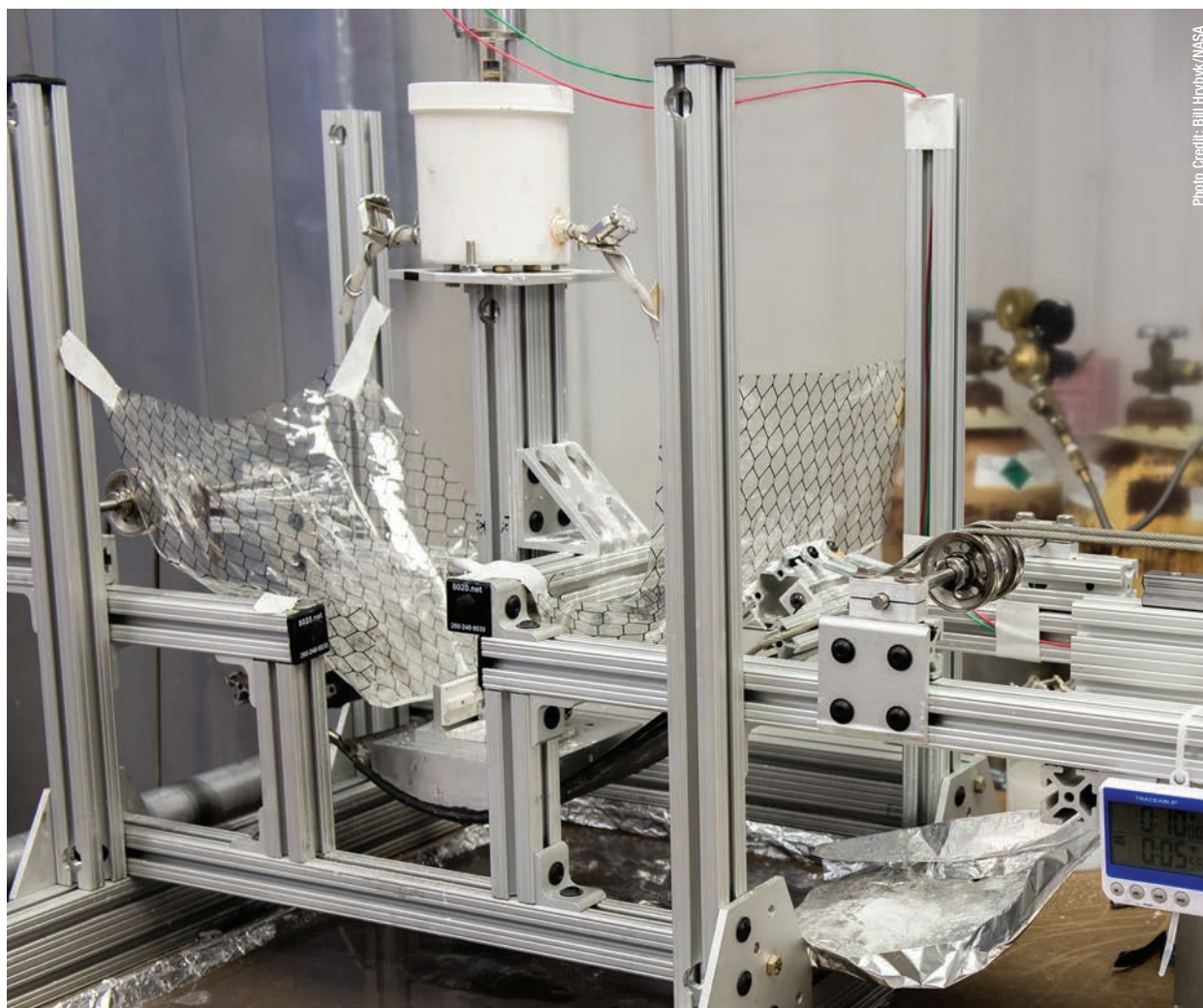


Photo Credit: Bill Hrybyk/NASA

Scientist Will Zhang has created a manufacturing facility to create a new-fangled X-ray optic made of silicon. This image shows the buffing machine to remove imperfections from the mirror's surface.

X-ray photons. With this special configuration, X-rays graze the mirrors' surfaces — like how a thrown pebble skims across the surface of a pond — rather than passing through them.

Silicon, which doesn't warp even when cut or exposed to fluctuating temperatures, offers a viable solution, Zhang said. "We have executed our mirror-making procedures many times," he added. "These represent the best lightweight X-ray mirrors ever. As a matter of fact, of all the astronomical X-ray mirrors that have been produced and flown, only Chandra's are better," he said, referring to one of NASA's Great Observatories, an X-ray mission that carries eight, very thick and heavy mirror segments, which are considered the highest-resolution X-ray mirrors ever launched. "But we aspire to match and then exceed Chandra's mirror quality before 2020."

Zhang intends to achieve that goal, in part, with NASA Strategic Astrophysics Technology funding. He and his team plan to further advance the non-conventional technology in preparation for a future X-ray mission that could be conducted aboard a mid-sized or a flagship-style mission.

## Old Hand at Mirror Making

Zhang is not a newcomer to the mirror-making business.

Fifteen years ago, he set out to develop a less-expensive, more efficient technique for crafting lightweight X-ray mirrors. He succeeded. Four years ago, he delivered 9,000 super-thin, curved glass mirrors for NASA's Nuclear Spectroscopic Telescope Array, or NuSTAR, mission using a novel manufacturing technique in which he placed thin pieces of commercially available glass on a mandrel and heated the entire assembly inside an oven — a process called slumping. As the glass heated, it softened and folded over the mandrel to produce a curved mirror that the Copenhagen-based Danish Technical University then coated with layers of silicon and tungsten to maximize its X-ray reflectance ([CuttingEdge, Winter 2012, Page 4](#)).

## Taking It to the Limit

Though Zhang proved the technique and produced thousands of modest-resolution mirrors ideal for NuSTAR, Zhang realized that he had taken the ap-



Photo Credit: Bill Hrybyk/NASA

*Thin, lightweight, high-resolution mirrors, such as the one shown here, are vital to next-generation X-ray missions. Will Zhang and Raul Riveros, are advancing a technique for manufacturing these optics using silicon.*

proach to its limit. "I spent a couple years trying to make slumped glass better. I got all the mileage I could get."

He got rid of eight of his 10 ovens used in the slumping process and turned his attention, instead, to single-crystal silicon, a material never polished and figured for X-ray mirrors.

Unbeknownst to him, another Goddard technologist, Vince Bly, had already investigated the material's use, ultimately producing a thick, yet lightweight spare mirror for the Goddard-built Thermal Infrared Sensor, one of two instruments developed for NASA's Landsat Data Continuity Mission ([CuttingEdge, Winter 2013, Page 10](#)). Though the mission didn't use the mirror because the optic never had flown in space, Bly said testing had proved its superiority.

When Zhang heard about Bly's work, he and Bly started working together, benefiting from each other's experience. "He used what we had done to solve his own problem," Bly said.

## No-Stress Silicon

The key, both said, lies with the material itself. Traditional materials for making mirrors — glass,

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ceramics, and metals — suffer from high internal stress, especially when cut or exposed to changing temperatures. These stresses become increasingly unpredictable as the mirror becomes thinner.

“Single crystal silicon is an excellent material for making spaceflight X-ray mirrors,” Zhang said. “It is inexpensive and abundantly available because of the semiconductor industry. Furthermore, it is a perfect material. It is immune from the internal stresses that can change the shape of X-ray mirrors made of glass.”

This is because every atom is arranged in a lattice configuration, which prevents the material from distorting even when cut or shaped. In other words, if a sheet of plywood were made of silicon, it would be perfectly flat and immune from warping, he said.

### Learned from Slumping

Zhang’s new process grows out of what he learned through glass slumping, he said. He takes a block of silicon and heats it. With a band saw, he creates the approximate shape and uses other machining tools and chemicals to further grind and refine the block’s surface. Like slicing cheese, he then cuts a

thin substrate measuring just a fraction of an inch in thickness from the block and polishes the surface. The last step is coating the individual segments with iridium to improve reflectance.

With his NASA funding, Zhang and his team are perfecting techniques for aligning and bonding 6,000 mirror segments to form meta-shells that would be integrated inside a mirror assembly projected to weigh about 200 pounds and stand just 1.6-feet tall. Ultimately, he would like to create six meta-shells and automate the alignment process.

“Making lightweight, high-resolution, relatively inexpensive X-ray mirrors has become my life’s work,” Zhang said. “When I started developing mirrors 15 years ago, I thought I’d get it done in a couple years. Fifteen years later, I’m still at it,” Zhang said. ♦

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## Brains of the Operation

### *Goddard Team Develops Modular Avionics Systems for Small Missions*

In just two years’ time, a team of Goddard engineers accomplished what some thought impossible: the group created a smaller, more capable “brain” for smaller spacecraft.

Led by Project Manager and Chief Engineer Noosha Haghani, the team leveraged years of knowledge to design a significantly smaller electronics system, called the Modular Unified Space Technology Avionics for Next Generation missions, or MUSTANG.

MUSTANG — through its use of mix-and-match electronics cards — acts as the mission’s brain and central nervous system, controlling every function needed to gather scientific data from a Small Explorer (SMEX)-type mission. This includes everything from spacecraft command and data handling to attitude control, power, and propulsion, to name just a few tasks. The team also developed a variation of the system — iMUSTANG — for instrument electronics and, like its sibling, it allows users to choose different capabilities depending on instrument needs.

“Key to MUSTANG’s success has been the integration of hardware and software design from day one,” said Deputy Director of Goddard’s Applied Engineering and Technology Directorate Craig Tooley, who spearheaded the effort. “It provides maximum processing performance and is highly flexible.”

### Two Versions Developed

The two MUSTANG variations give NASA mission and instrument developers a smaller, highly modular, off-the-shelf avionics system that can be customized to meet virtually any smaller-mission requirement — and, better yet, at a reduced cost, Haghani added. While inappropriate for some large, flagship-style spacecraft, MUSTANG suits cost-constrained, yet high-performance missions developed in-house at Goddard, Haghani said.

“One of our goals was to create an avionics system that mission planners would not have to redesign for each mission,” said Pete Spidaliere, a Goddard engineer who participated in MUSTANG’s develop-

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ment. "We wanted to give the center a new way of doing things," Haghani added. "In the past, everyone wanted to start from scratch and develop their own avionics systems, which is expensive. By using MUSTANG and iMUSTANG, developers can focus their time and resources on their missions and instruments, not the electronics running them."

In a related development, another Goddard team now is taking lessons

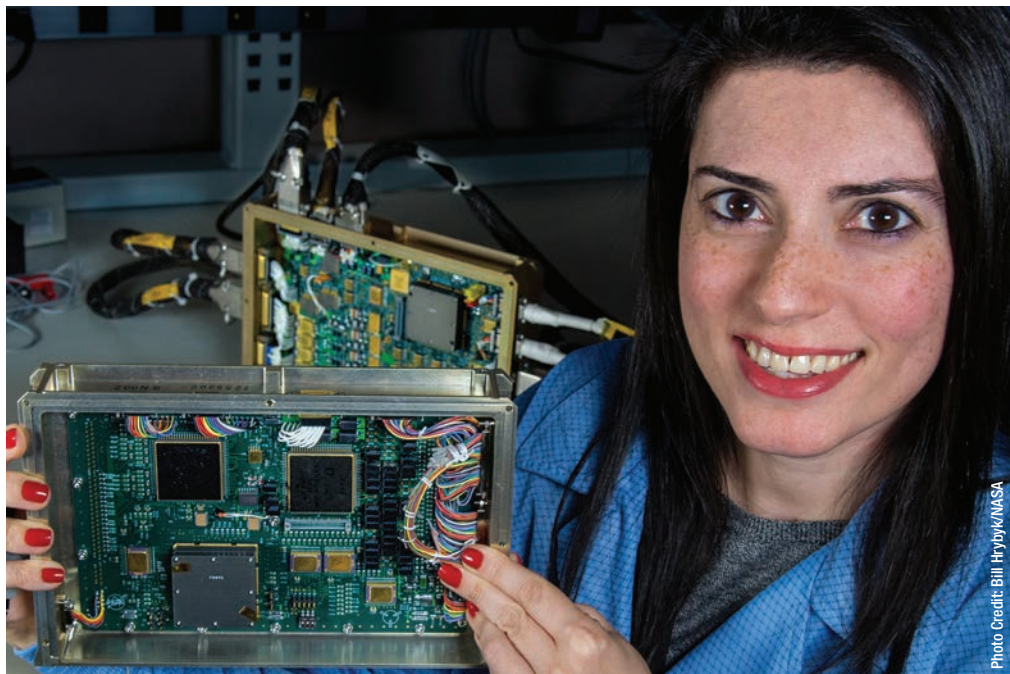
learned from MUSTANG's creation to build a similar-type avionics system for even smaller spacecraft, including tiny CubeSats (see related story, page 7). Between the two systems, Goddard will be able to accommodate the avionics needs of a broad range of small to diminutive spacecraft and many different instruments, as well.

Already, the two MUSTANG variations have attracted users. NASA's Pre-Aerosols Clouds and Ocean Ecosystems mission, or PACE, and the Global Ecosystems Dynamics Investigation, or GEDI, have selected MUSTANG to run their operations and are funding the development of additional capabilities that could be used in other future NASA missions. Meanwhile, one of PACE's baselined instruments, the Ocean Color Instrument, or OCI, plans to employ iMUSTANG.

## MMS Heritage

The effort to craft a modular avionics system began about two years ago just as Goddard engineers were putting the finishing touches on the four spacecraft that make up NASA's Magnetospheric Multi-scale, or MMS, mission.

It became obvious to Tooley, who also served as MMS project manager, that the center could reduce the cost of spacecraft electronics — traditionally an expensive, multi-million-dollar undertaking — and become more competitive by offering an off-the-shelf, ala-carte avionics system that users could



*Goddard technologist Noosha Haghani holds one of many electronics cards, which she and her team designed for a new avionics system called MUSTANG. MUSTANG has been baselined for two upcoming NASA missions.*

Photo Credit: Bill Hyduk/NASA

customize to meet their own needs. "The motivation is to keep board redesign costs to a minimum and allow Goddard to become competitive in proposal development and winning in-house work for the center," Haghani said.

## Smaller by Half

Taking MMS's avionics system, the MUSTANG team reduced by half the size of the housing box and began designing and testing a core set of cards controlling vital spacecraft functions. Since then, the group created 22 lightweight, highly capable cards, including one that controls higher-speed communications of up to 1.2 gigabits per second. MUSTANG was born.

"We took the MMS designs, shrunk them down, and added some powerful capabilities," Spidaliere said, adding that the team cut costs by a factor of three and crafted a system that is lighter and more robust than anything built before at Goddard.

"One of the great things about this effort and Noosha's team is that they did the impossible," Spidaliere added, alluding to the effort that resulted in a wholly new avionics system in less than two years. "It never dawned on them that this couldn't be done." ♦

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# Raising the Curve

*Goddard Team Advances SmallSat Reliability*

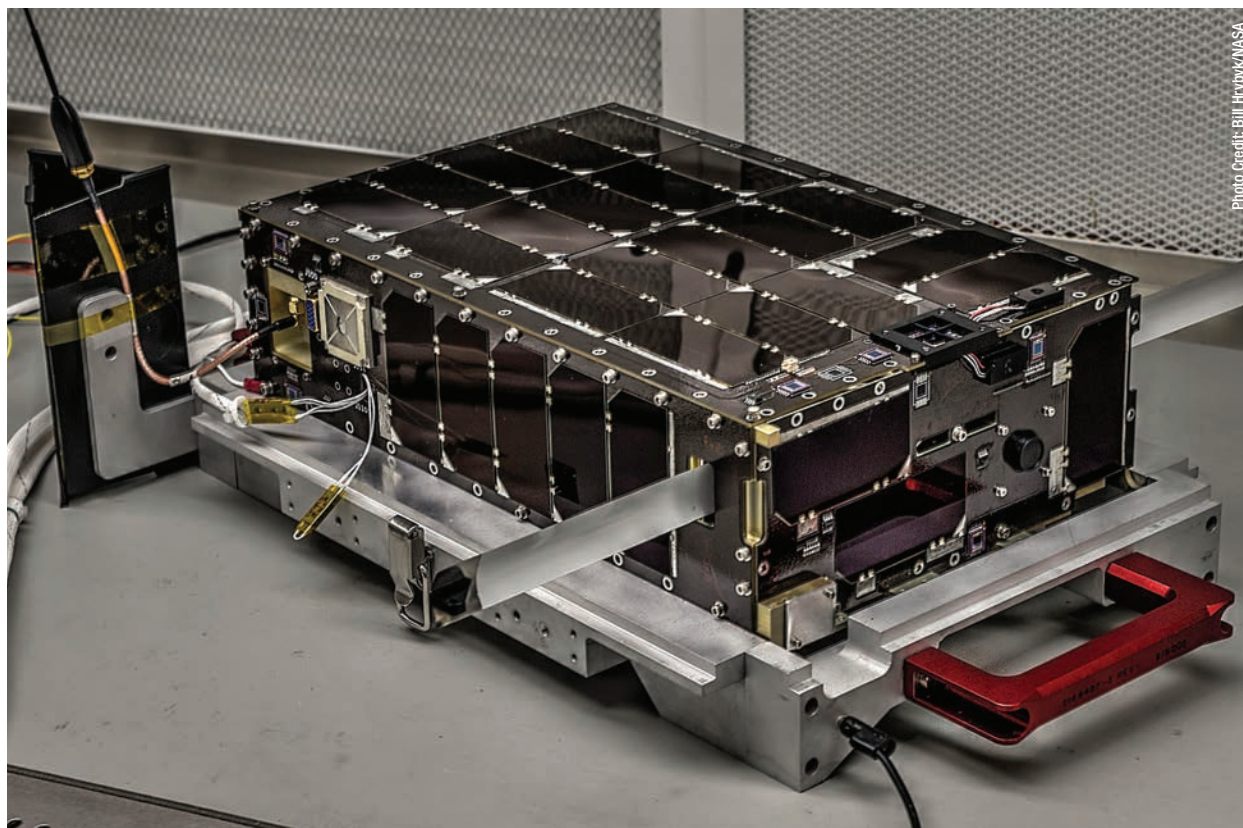


Photo Credit: Bill Kryby/NASA

*Dellinger's exterior is lined with solar panels. Slightly larger than a cereal box, Dellinger is a 6U CubeSat — indicating that its volume is about six liters.*

When a tiger team set out to design, build, integrate, and test a large shoebox-sized satellite capable of executing NASA-class science, the group didn't completely appreciate the challenges it would face. It knows now. And because of the experience, Goddard currently is spearheading initiatives to dramatically improve the reliability of small satellite-based systems and missions.

Although the six-unit, or 6U, Dellinger spacecraft is nearly finished and awaiting launch to the International Space Station in June 2017, it took double the time and more funds than budgeted to build a robust CubeSat mission capable of achieving NASA-quality science ([CuttingEdge, Fall 2014, Page 4](#)).

No one, however, is calling the project a failure.

## Underscoring a Hard Truth

The experience underscored a hard truth, said Michael Johnson, the chief technologist of Goddard's Applied Engineering and Technology Directorate,

who championed the Dellinger pilot project.

"In many cases, our desired level of performance wasn't there," he said, referring to many small satellite-related components and subsystems offered by commercial vendors. "The Dellinger team encountered more than a handful of technical challenges with components right out of the box that affected the project's cost and schedule. This wasn't a theoretical activity. Some of the systems simply did not meet our expectations."

Created in 1999 by the California Polytechnic State University primarily as a learning tool, the CubeSat platform has grown in popularity among organizations worldwide mainly because they offer less-expensive access to space. Many CubeSats, however, are notoriously unreliable. They are analogous to the early days of the rocket program, with a mission-failure rate exceeding 40 percent, Johnson explained.

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"There are many reasons for mission failure — some known, and some hypothesized. Nonetheless, this challenge will be compounded as small satellites, or SmallSats, leave the relatively benign radiation environment of low-Earth orbit and start to explore other regions of the solar system," Johnson said.

### GMSA Initiated

Consequently, Johnson and a team of other experts initiated the Goddard Modular SmallSat Architecture, or GMSA. The effort is aimed at developing overarching system designs and technologies to dramatically reduce SmallSat mission risks without significantly increasing the platforms' cost. As part of this initiative that also addresses mitigating the adverse effects of radiation, Goddard technologists have made progress developing new mission-critical command and data handling and electrical power-system technologies, he said.

"We want to raise the curve and advance the robustness of the small-satellite platform," Johnson said.

Motivating the initiative is the fact that lower-cost SmallSat platforms — of which CubeSats are a subclass — can provide multi-point or distributed measurements when flown as a constellation. This type of mission architecture is made more feasible by smaller, cost-effective platforms. Distributed spacecraft missions offer the potential to observe phenomena not possible with a single spacecraft.

"We won't be able to achieve the full potential of SmallSats if we can't achieve targeted levels of mission reliability," Johnson said. "How do we apply the breadth of knowledge we have with large satellites and apply them to SmallSats without driving up costs? That's the challenge."

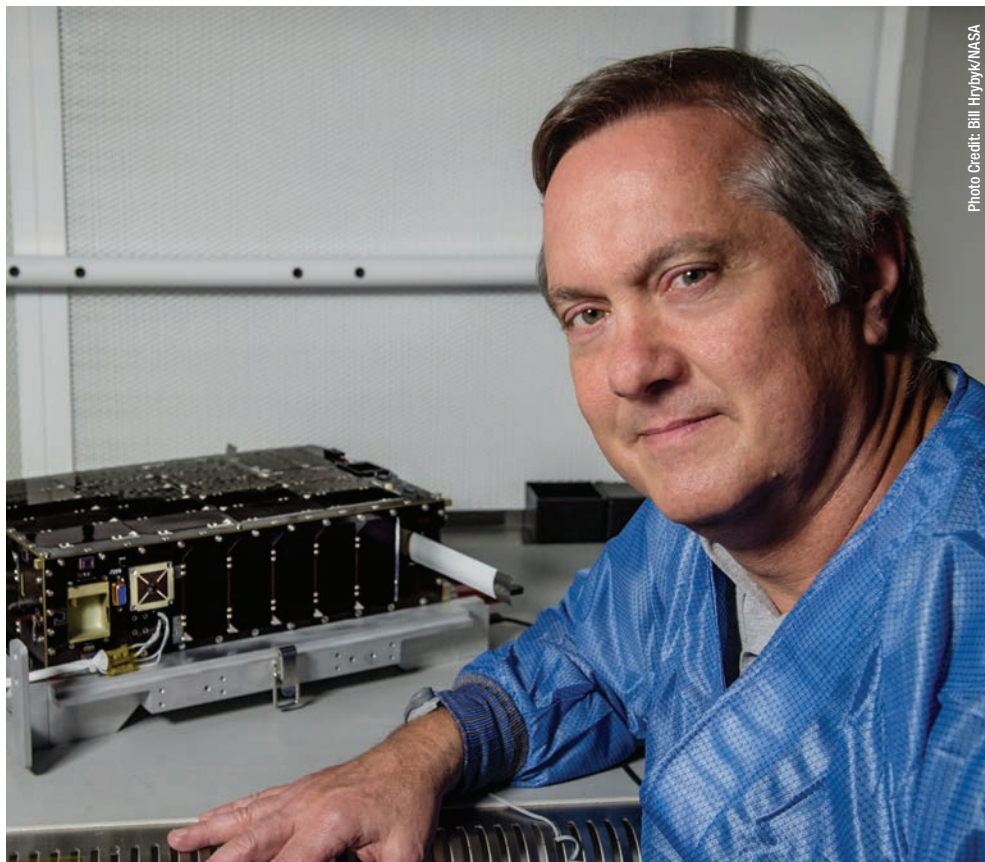


Photo Credit: Bill Hrybyk/NASA

Project Manager Chuck Clagett helped design and build the 6U Dellingr spacecraft, which Goddard purposely developed to support NASA-quality science on a small platform. Among other instruments, Dellingr carries two no-boom magnetometers, a first for miniature satellites.

### Goddard Creates Rad-Tolerant Avionics

Embracing the challenge is Goddard engineer James Fraction. An expert in avionics systems, Fraction won Goddard Internal Research and Development, or IRAD, program awards in FY15 and FY16 to design a general-purpose, radiation-tolerant avionics system for SmallSats — literally the spacecraft's brain that handles everything from command and data handling to communications, attitude control, and power.

"What we wanted to do was increase the reliability of SmallSat electronics," Fraction said. "The challenge is which commercially available components to use and how to use them."

By offering mission planners a basic avionics system tolerant of radiation upsets — that is, the system can handle high-energy particle hits that sometimes cause electronic systems to latch-up and draw destructive excessive current — the team knew it would be addressing a mission-critical need.

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Leveraging insights gained when he helped develop Goddard's Modular Unified Space Technology Avionics for Next Generation missions, or MUS-TANG — a mix-and-match avionics system for Explorer-class missions (see related story, page 5) — Fraction began work on the so-called SmallSat Common Electronics Board, or SCEB, and an adaptor board.

The effort has gone well, he said. "We've been getting a lot of interest, actually," he said, adding that his technology already has been baselined

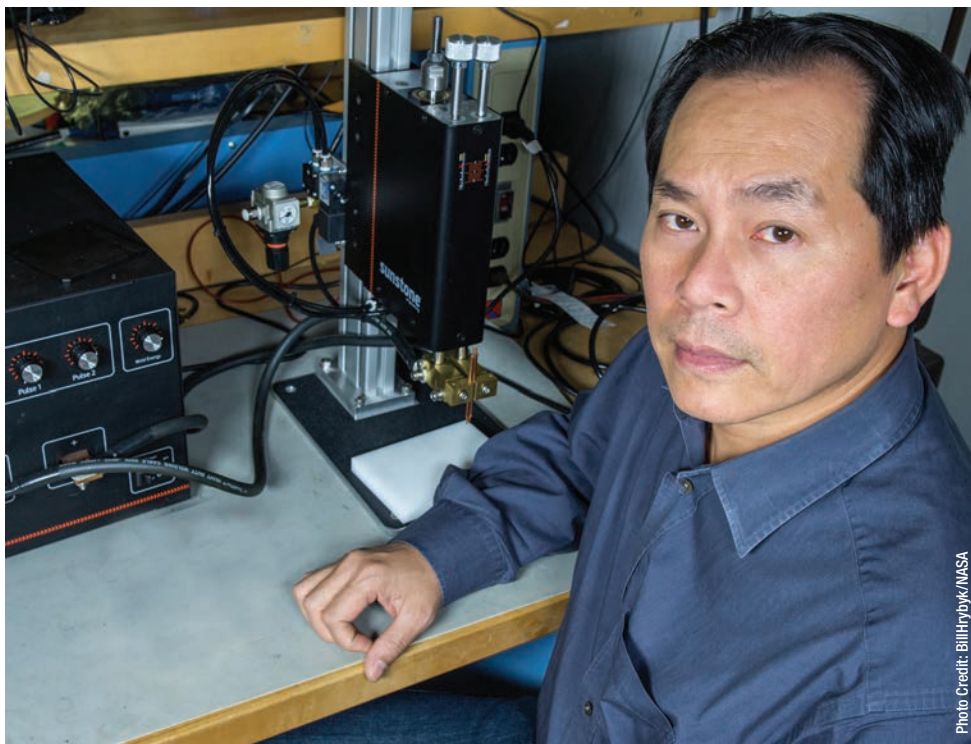
for a handful of proposed missions. "My goal or philosophy is the 'field of dreams.' Build it and they will come," Fraction said.

## Complementary GMSA-Compatible Technologies

In a related effort, Principal Investigator Hanson Nguyen is advancing two complementary technologies: more reliable, miniaturized lithium-ion batteries and power-system electronics that would be used in conjunction with the avionics system. "Together, the power-system electronics, the battery, and SCEB will provide the miniaturization, flexibility, and reliability required by GMSA," Nguyen said.

Like Fraction, Nguyen was motivated by general performance risks associated with many commercially available batteries and power electronics, realizing that if Goddard wanted to enable many of the missions envisioned by his science colleagues, he would have to tackle the challenge head on.

"Our proposed science missions will be in low-Earth orbit and beyond, and will typically operate for one to two years," Nguyen said, offering one of the reasons he initiated the battery-development effort. "I contacted two well-known CubeSat battery vendors, and we are concerned that the vendors' battery designs include some components that



*Hanson Nguyen characterized lithium-ion rechargeable cells and designed a flight battery suitable for SmallSat missions. He also developed SmallSat power-system electronics, which he is now integrating and testing with the battery.*

may not have the radiation tolerance and reliability needed for these types of missions." His research also revealed that most SmallSat missions couldn't afford the space-qualified batteries from other vendors supplying NASA's larger missions, which have larger budgets.

The only near-term solution was to design something in house. With IRAD funding, Nguyen characterized lithium-ion rechargeable cells and designed a flight battery suitable for SmallSat missions. At the same time, he developed the power-system electronics.

## Dellinger: Money Well Spent

Had the Dellinger effort gone off without a hitch, it's possible Johnson would have never anticipated the need for GMSA, which he sees as a mid-term solution that has evolved into a more comprehensive SmallSat initiative involving other NASA centers, government agencies, and industry. "Every penny spent (on Dellinger) was a penny well spent," he said. "It led to many findings that are informing our next steps. ♦

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## SPECIAL REPORT : Out-There Space Technologies

NASA's Center Innovation Fund, or CIF, is purposely designed to advance high-risk, potentially groundbreaking, "out-there" technologies that would feel at home in science fiction novels. Here, we highlight two — a new origami-inspired radiator for CubeSats and a spectrom-

eter based on quantum dots, which would eliminate the need for gratings, prisms, and moving parts found in most traditional spectrometers. Both technologies are early in their development, but with CIF funding could prove invaluable to future NASA missions.

# The Art of Paper Folding Inspires New Shape-Shifting Radiator

Japan's ancient art of paper folding has inspired the design of a potentially trailblazing "smart" radiator that could remove or retain heat on small satellites.

Goddard technologist Vivek Dwivedi has teamed with a couple of researchers at Brigham Young University in Utah to advance an unconventional radiator that would fold and unfold, much like the V-groove paper structures created with origami, the art of transforming a flat piece of paper into a finished sculpture.

Under a NASA research grant, Brigham Young University assistant professor Brian Iverson and doctoral student Rydge Mulford are advancing the design of a three-dimensional, foldable radiator. Meanwhile, Dwivedi is developing a coating to enhance the radiator's heat-shedding or conservation capabilities.

This novel radiator controls the rate of heat loss by performing shape-shifting maneuvers. The resulting topographical changes could be achieved with temperature-sensitive materials like muscle wire or shape-memory alloys. As temperature-sensitive materials experience a change in temperature — caused by spacecraft electronics or the absorption of heat from the Earth or sun — the radiator could automatically change its shape to either shed or conserve heat.

The deeper the folds or cavities, the greater the absorption, explained Mulford, adding that scientists have investigated the use of cavities to effect heat loss for nearly 100 years, but no one has approached the challenge in quite this way. "Origami allows you to change the depth of these cavities in real time, thereby changing the heat loss from a surface in real time," he said.

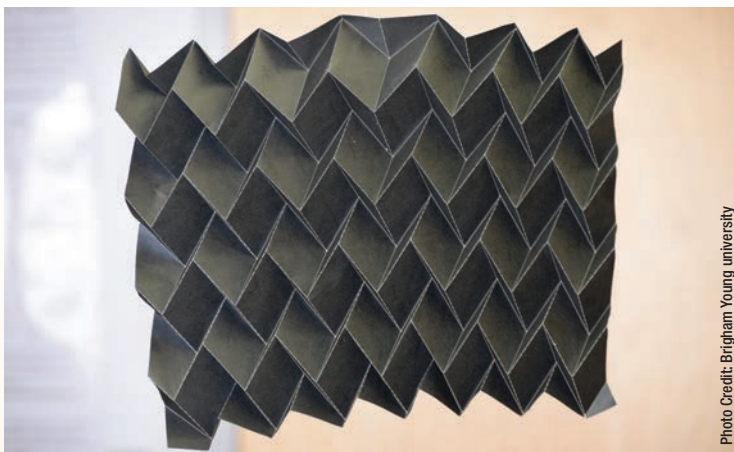


Photo Credit: Brigham Young University

Brigham Young assistant professor Brian Iverson and doctoral student Rydge Mulford have teamed with Goddard technologist Vivek Dwivedi to advance the design of a three-dimensional, foldable radiator, inspired by the art of paper folding. Iverson and Mulford are experimenting with different shapes to determine which configuration would work best as a radiator.

## One Step Further

The team, however, wants to take the concept one step further.

Dwivedi, meanwhile, is working to advance a highly emissive coating principally made of vanadium oxide, a transition metal oxide. Dwivedi's idea is to then apply the special coating on the origami radiator. Dwivedi also is investigating the coating's use on other spacecraft components, including solar-array panels.

In testing, vanadium-oxide has shown that it transitions from a semiconductor to a metal state when it reaches 154 degrees Fahrenheit. The changeover causes an increase in emissivity, Dwivedi said. Because satellites encounter wildly fluctuating temperature changes on orbit, Dwivedi's goal is to lower the transition temperature.

In collaboration with University of Maryland Professor Raymond Adomaitis, he plans to lower the

*Continued on page 12*



# Goddard and MIT Collaborate to Develop Quantum-Dot Spectrometer for Use in Space

A Goddard technologist has teamed with the inventor of a new nanotechnology that could transform the way space scientists build spectrometers, the all-important instrument used by virtually all scientific disciplines to measure the properties of light emanating from astronomical objects, including Earth itself.

Research engineer Mahmooda Sultana now is collaborating with Mounji Bawendi, a chemistry professor at the Cambridge-based Massachusetts Institute of Technology, or MIT, to develop a prototype imaging spectrometer based on the emerging quantum-dot technology that Bawendi's group pioneered.

## Introducing Quantum Dots

Quantum dots are a type of semiconductor nanocrystal discovered in the early 1980s. Invisible to the naked eye, the dots have proven in testing to absorb different wavelengths of light depending on their size, shape, and chemical composition. The technology is promising to any applications that rely on the analysis of light, including smartphone cameras, medical devices, and environmental-testing equipment.

"This is as novel as it gets," Sultana said, referring to the technology that she believes could miniaturize and potentially revolutionize space-based spectrom-

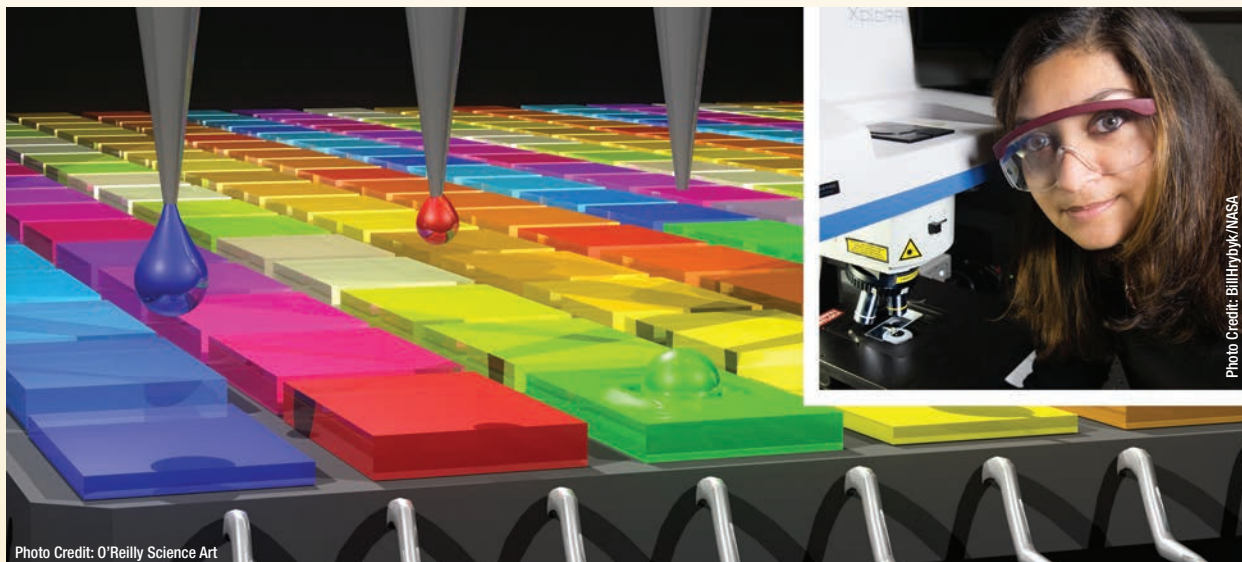
eters, particularly those used on uninhabited aerial vehicles and small satellites. "It really could simplify instrument integration."

Absorption spectrometers, as their name implies, measure the absorption of light as a function of frequency or wavelength due to its interaction with a sample, such as atmospheric gases. After passing through or interacting with the sample, the light reaches the spectrometer. Traditional spectrometers use gratings, prisms, or interference filters to split the light into its component wavelengths, which their detector pixels then detect to produce spectra. The more intense the absorption in the spectra, the greater the presence of a specific chemical.

While space-based spectrometers are getting smaller due to miniaturization, they still are relatively large, Sultana said. "Higher-spectral resolution requires long optical paths for instruments that use gratings and prisms. This often results in large instruments. Whereas here, with quantum dots that act like filters and absorb different wavelengths depending on their size, shape, and composition, we can make an ultra-compact instrument. In other words, you could eliminate optical parts, like gratings, prisms, and interference filters."

Just as important, the technology allows the instru-

*Continued on page 12*



*This illustration shows how a device prints the quantum dot filters that absorb different wavelengths of light depending on their size and composition. The emerging technology could give scientists a more flexible, cost-effective approach for developing spectrometers, a commonly used instrument. **INSET:** Principal Investigator Mahmooda Sultana has teamed with the Massachusetts Institute of Technology to develop a spectrometer for use in space. In this photo, she is characterizing the optical properties of the quantum-dot pixels.*

## Shape-Shifting Radiator, *continued from page 10*

transition temperature by applying very thin films of silver and titanium to the vanadium-oxide using sputtering and a technique called atomic layer deposition, or ALD. ALD is performed in a state-of-the-art reactor developed by both Dwivedi and Adomaitis. With ALD, engineers literally can apply atomic-sized layers of different materials onto intricately shaped structures — much like making lasagna (*CuttingEdge*, Spring 2012, Page 6).

### First-of-a-Kind Combination

"The combination of origami and a vanadium-oxide-based coating would be the first time two different variable emissivity devices have been combined into one structure," Iverson said.

By combining both technologies, the team believes it can create a smaller, more efficient radiator ideal for use on CubeSats. Such a radiator, Iverson said, could be easily attached to any spacecraft surface where heat needed to be rejected.

While early in its development, the origami radiator couldn't come too soon, particularly for use on CubeSats. Traditional radiators typically are flat and



Vivek Dwivedi, who is standing in front of a sputtering reactor used to deposit vanadium-oxide onto sample substrates for testing, is collaborating with Brigham Young University researchers to develop a radiator ideal for small spacecraft.

heavy, not lending themselves to installation on a satellite measuring as little as four inches on a side.

"This approach has the potential to be a game changer in thermal design," Dwivedi said. "Our goal is to replace traditional radiators with dynamic ones, period." ♦

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## Quantum Dots, *continued from page 11*

ment developer to generate nearly an unlimited number of different dots. As their size decreases, the wavelength of the light that the quantum dots will absorb decreases. "This makes it possible to produce a continuously tunable, yet distinct, set of absorptive filters where each pixel is made of a quantum dot of a specific size, shape, or composition. We would have precise control over what each dot absorbs. We could literally customize the instrument to observe many different bands simultaneously with high spectral resolution."

### Prototype Instrument Under Development

With her Center Innovation Fund support, Sultana is working to develop, qualify through thermal vacuum and vibration tests, and demonstrate a 20-by-20 quantum-dot array sensitive to visible wavelengths needed to image the sun and the aurora. However,

the technology can be easily expanded to cover a broader range of wavelengths, from ultraviolet to mid-infrared, which may find many potential space applications in Earth science, heliophysics, and planetary science, she said.

Under the collaboration, Sultana is developing an instrument concept particularly for a CubeSat application and MIT doctoral student Jason Yoo is investigating techniques for synthesizing different precursor chemicals to create the dots and then printing them onto a suitable substrate. "Ultimately, we would want to print the dots directly onto the detector pixels," she said.

"This is a very innovative technology," Sultana added, conceding that it is very early in its development. "But we're trying to raise its technology-readiness level very quickly. Several space-science opportunities that could benefit are in the pipeline." ♦

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# G-LiHT Proves Value to Scientists

*R&D-Funded Instrument to Inventory Alaskan Forests*

If instruments could accrue frequent-flyer points, Goddard's Lidar, Hyperspectral, and Thermal Airborne Imager, also known as G-LiHT, already would have earned an upgrade or two or perhaps entry into the VIP lounge.

Since its commissioning in June 2011, G-LiHT has become something of a workhorse for scientists interested in simultaneously mapping the composition, structure, and health of terrestrial ecosystems. With nearly 1,000 science flight hours under its belt, G-LiHT doesn't appear to be retiring anytime soon, either.

Led by Principal Investigator Bruce Cook, the G-LiHT team recently secured NASA funding to continue monitoring U.S. forests in the interior of Alaska as part of a joint project with the U.S. Forest Service's Forest Inventory and Analysis program. The instrument also is being deployed in 2017 as part of NASA's Fluorescence Airborne Research Experiment to improve interpretation of data from the European Space Agency's new Fluorescence Explorer. And early in 2017, G-LiHT will fly in a campaign over Puerto Rico to study rates of regrowth in tropical forests.

Used by NASA and many other federal agencies, G-LiHT has been used to inventory and monitor forest carbon stocks in the U.S. and Mexico, detect forest insect and disease outbreaks in New England, study regrowth rates in tropical forests, and cross-validate NASA's Earth-observing satellites. Brandeis University anthropologist Charles Golden has even mined open-access G-LiHT data to study pre-Columbian land-use and settlement patterns in southern Mexico.

G-LiHT data is so important to the U.S. Forest Service, or USFS, that the agency is funding Cook's team to upgrade the system, replacing five-year-



*Larry Corp operates G-LiHT in the U.S. Forest Service's Cessna aircraft. The instrument has become the go-to instrument for simultaneously mapping the composition, structure, and health of terrestrial ecosystems.*

old instruments with higher-fidelity models that offer greater redundancy and precision.

## "Victims of Our Own Success"

"G-LiHT is a huge success story," said Cook, referring to the highly portable, airborne imaging system initially developed through the Goddard Internal Research and Development program. "We are victims of our own success. More and more people are requesting G-LiHT acquisitions for their own research studies and applications."

*Continued on page 16*

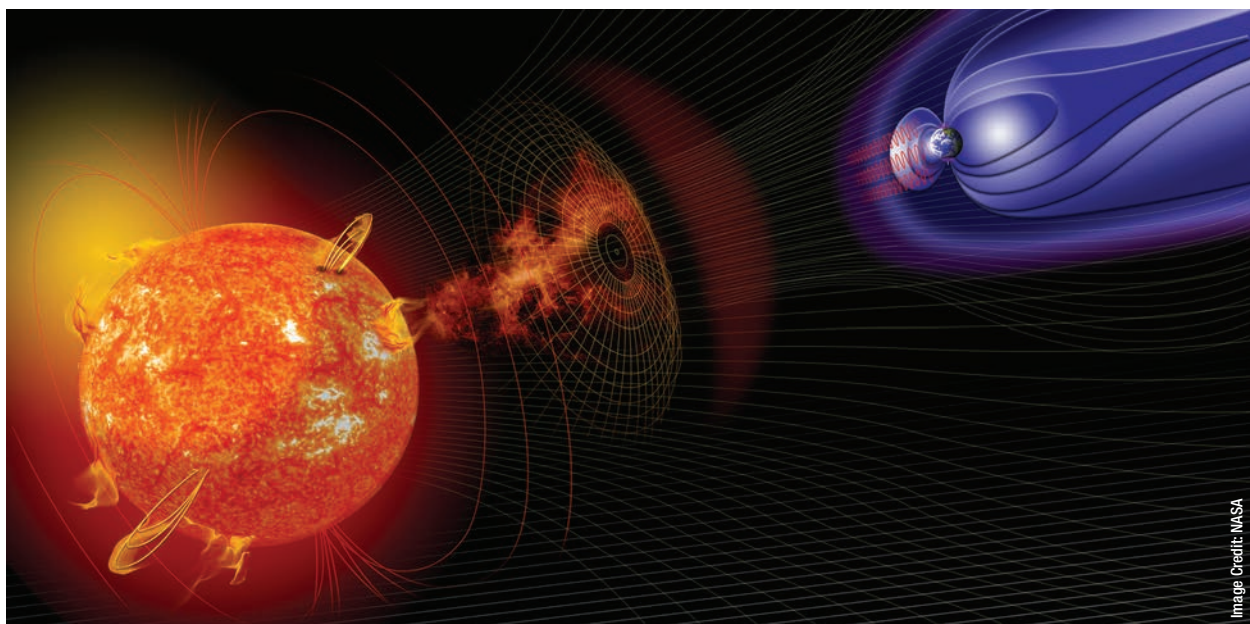
## Spotlight on Innovative Scientific Research

At the request of NASA Headquarters, Goddard Chief Scientist Jim Garvin initiated a pilot program five years ago to provide funding to NASA scientists for highly innovative scientific research that might not otherwise receive support via more traditional funding programs. What he and his Goddard colleagues envisioned was a program like NASA's Center Innovation Fund, which NASA purposely created to advance potentially revolu-

tionary space technologies (see page 10). So successful was the Goddard pilot that NASA agreed to continue the program and extend it to all centers. Called the Science Innovation Fund, or SIF, NASA funded 19 investigations proposed by Goddard scientists in 2016-2017. Here, we spotlight a research effort to determine a link between marine-mammal strandings and space weather.

## Storms and Strandings

*Scientists Collaborate to Discover Whether Solar Storms Cause Animal Beachings*



The artist's illustration shows how events on the sun change the conditions in near-Earth space. A Goddard scientist is investigating if solar storms are linked to marine-mammal strandings that occur worldwide.

A long-standing mystery among marine biologists is why otherwise healthy whales, dolphins, and porpoises — collectively known as cetaceans — end up getting stranded along coastal areas worldwide. Could severe solar storms, which affect Earth's magnetic fields, be short-circuiting their internal compasses and causing them to lose their way?

Although some have postulated this and other theories, no one has ever initiated a thorough study to determine whether a relationship exists — until now. Goddard heliophysicist Antti Pulkkinen has teamed with the federal Bureau of Ocean Energy Management, or BOEM, and the International Fund for Animal Welfare, or IFAW, to determine whether a link exists.

Strandings occur around the world, involving as few as three to as many as several hundred animals per

event. Although a global phenomenon, such strandings tend to happen more often in New Zealand, Australia, and Cape Cod, Massachusetts, said project collaborator Katie Moore, the director of IFAW's global Animal Rescue Program. Headquartered in Yarmouth Port, Massachusetts, IFAW operates in 40 countries, rescuing animals and promoting conservation to secure a safe habitat for wildlife.

"These locations share some key characteristics, such as the geography, gently sloping beaches, and fine-grained sediment, which we think all play some role in these events," she said.

### Skewed Compasses

Another possibility is that these animals' internal compasses are somehow skewed by humans' use

*Continued on page 15*



of multi-beam echo sounders and other sonar-type equipment used to map the seafloor or locate potential fishing sites, to name just a few applications.

"However, these human-made influences do not explain most of the strandings," said Pulkkinen, an expert in space weather and its effect on Earth. "Theories as to the cause include magnetic anomalies and meteorological events, such as extreme tides during a new moon and coastal storms, which are thought to disorient the animals. It has been speculated that due to the possible magnetic-field sensing used by these animals to navigate, magnetic anomalies could be at least partially responsible."

Indeed, magnetic anomalies caused when the sun's corona ejects gigantic bubbles of charged particles out into the solar system can wreak havoc on Earth-orbiting satellites and power grids when they slam into Earth's protective magnetosphere. It's possible they could affect animals, as well, Pulkkinen said.

"The type of data that Antti has accumulated, together with the extensive stranding data at our disposal will allow us to undertake the first rigorous analysis to test possible links between cetacean mass strandings and space-weather phenomena," said Desray Reeb, a marine biologist at BOEM's Headquarters in Sterling, Virginia. Reeb approached Pulkkinen about launching a research effort after hearing his presentation about space weather in June 2015.

## Massive Data-Mining Effort

Funded by NASA's Science Innovation Fund and BOEM, Pulkkinen and his collaborators are carrying out a massive data-mining operation. The team will analyze NASA's large space-weather databases, including field recordings and space observations, and stranding data gathered by BOEM and IFAW.

"We estimate that records on the order of hundreds of cetacean mass strandings will be available for

study, thus making our analyses statistically significant," Pulkkinen said. "We therefore expect that we will be able to reliably test the hypothesis. So far, there has been very little quantitative research, just a lot of speculation," Pulkkinen continued. "What we're going to do is throw cold, hard data at this. It's a long-standing mystery and it's important that we figure out what's going on."

The team expects to complete the study by the end of the fiscal year and publish its findings in a scientific, peer-reviewed journal. Should the study reveal a statistical correlation, team members said the results won't necessarily imply a causal link. However, it would provide the first step toward determining if space weather contributes to the beachings.



*Each year hundreds of whales, porpoises, and dolphins lose their way and become stranded. A team is investigating if solar storms contribute to the phenomenon.*

## "Save More Animals"

"The results of this study will be informative for researchers, stranding network organizers, resource agencies and regulatory agencies," Reeb said. "If we understand the relationship between the two, we may be able to use observations of solar storms as an early warning for potential strandings to occur," added Moore, who said she "was immediately keen" to get involved in the study.

"This would allow stranding responders in global hotspots, and really around the world, to be better prepared to respond, thus having the opportunity to save more animals," Moore said. ♦

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## G-LiHT, *continued from page 13*

The instrument's value stems in large part from its integration of six commercial-off-the-shelf, or COTS, instruments and an automated data-processing and distribution system with a user-friendly Web interface. G-LiHT's innovation lies in how Cook's team integrated the devices into a highly portable, 80-pound package that can be operated on general-aviation aircraft.

Currently, the G-LiHT package includes a scanning-lidar system to provide 3-D information about the distribution of foliage and tree canopies; imaging and irradiance spectrometers to discern the composition of plant and tree species; a thermal imager to detect plant stress; a fine-resolution stereo-imaging camera to collect centimeter-scale information about branching and coarse woody debris; and a GPS receiver to calculate location.

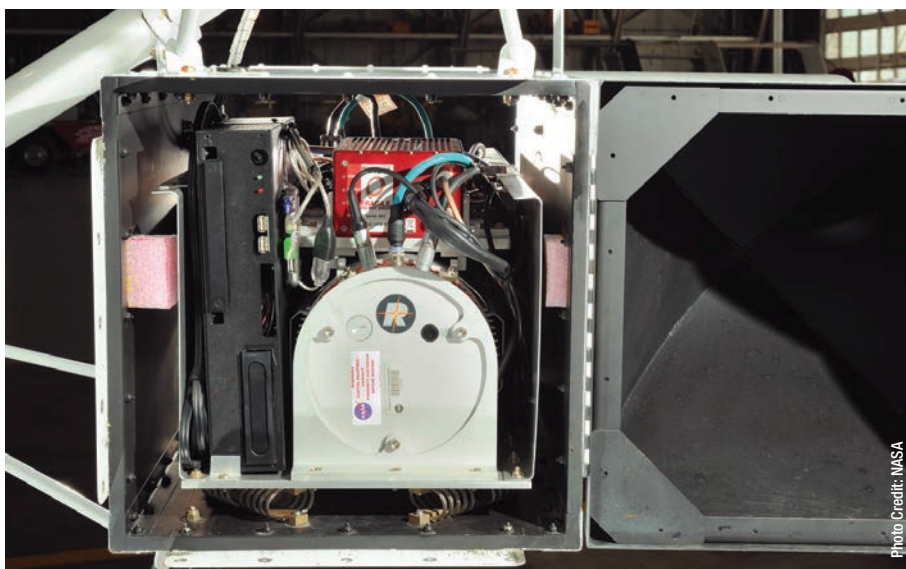
Although commercial vendors can provide independent lidar, spectroscopic, and thermal data products, no provider collects all three data types in a single pass. Having this ability allows scientists to simultaneously collect fine-resolution data that is coincident in both space and time. This is both cost effective and critical to data analysis, and is helping scientists understand the health and wellbeing of terrestrial ecosystems, Cook said.

## Collaboration Continues

With the new NASA funding, the G-LiHT team, which also includes Larry Corp, Douglas Morton, Anika Holata, Joel McCorkel, and Jyoteshwar Nagol, will extend the collection of G-LiHT data into the Susitna-Copper River forest inventory unit in interior Alaska during 2018.

"These remote regions are difficult and expensive to monitor with standard field methods," Cook said. "Recent warming and projected future impacts from climate change on forest carbon stocks, composition, and extent have elevated the need to develop new approaches for forest monitoring in Alaska."

The joint-agency program, funded by the USFS's Pacific Northwest Research Station and NASA's Carbon Monitoring System, began in 2014 as a pilot project to inventory forest resources in the Tanana Valley of interior Alaska, a region the size of Iowa. Although the USFS maintains one of the largest



*This image shows the highly successful G-LiHT instrument nestled inside a wing pod during its first deployment. Since then, the instrument has racked up nearly 1,000 science flight hours.*

networks of permanent forest inventory plots in the world, until recently the database didn't include thousands of miles of forested land in interior Alaska.

Due to the success of the pilot project, the USFS initiated a 10-year, \$25-million inventory plan for the rest of interior Alaska. The ultimate goal, Cook said, is estimating the total volume of live and dead trees, including woody shrubs, using G-LiHT airborne data to augment USFS's inventory plots. These estimates will provide critical and timely information for carbon monitoring and resource management. ♦

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Goddard's Emerging Technologies

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